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Abrasion Tests of Concrete for Pavements

By

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and

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A Thesis Submitted For
The Degree Of Bachelor Of Science
Civil Engineering Course

University of Wisconsin

1917

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Abrasion Tests of Concrete for Pavements

The tests were made in the materials testing laboratory at the University of Wisconsin, during the school year of 1916 and 1917, by the authors, under the direction of Professor M.O. Withey.

Scope of the Work. - The materials used in these tests consisted of five coarse aggregates and two fine aggregates. The coarse aggregates used were Janesville gravel from Janesville, Wisconsin, Lohrville granite from Lohrville, Wisconsin, Kettle River sandstone from Sandstone, Minnesota, Niagara limestone from Racine, Wisconsin and lower magnesian limestone from Madison, Wisconsin. The fine aggregates used were bank sand from Janesville, Wisconsin and Lohrville granite screenings from Lohrville, Wisconsin. Tension tests, compression tests and abrasion tests were made of concrete made from the above named materials.

Acknowledgement. - The thanks of the authors are due to Mr.Gordon A. Beebe as well as to Professor Abrams for valuable suggestions obtained from their work along a similar line. Especial acknowledgement is due to Professor Withey for many valuable suggestions and advice. The majority of the tests were made by Mr.Davis and Mr.Holmes but owing to the withdrawal from school of Mr.Davis to enter the military training the tests were completed and the thesis written by Mr.Holmes.

Present State of Development in Use of Concrete for Roads.

Concrete has but very recently come into use as a road-building material and consequently no satisfactory methods have been standardized for testing it. At present the tests applied

to concrete for pavements consist of tests of the aggregates. It is usually specified that the coarse aggregate must have a certain crushing strength and a certain coefficient of hardness as shown by a Deval abrasion test.

The results of such tests are not reliable indications of the wearing qualities in a pavement.
In as much as concrete makes a cheap and durable pavement where it is properly constructed and many miles of such pavements are being built in the United States every year,it follows that there is a need of some standard test by means of which the wearing qualities of aggregates for concrete may be accurately foretold.

Relation of Proposed Work to Previous Work. - Abrasion tests of concrete similar to those described in this thesis have been made by Professor Charles F.Shoop of the University of Minnesota, by Mr.Gordon A.Beebe of the University of Wisconsin and by Professor Abrams of Lewis Institute. The present work differs from theirs however in that different materials were used and the specimens tested were of a different form.

Statement of Purpose. - The purpose of the tests, described in this thesis, was to study the relative resistance to abrasive wear of concretes made from various materials and to develop a test which could easily be applied to testing concrete for use in pavements.

General Theory.

The wearing action to which a pavement is subjected is difficult to approximate in the laboratory. An automobile traveling over a pavement subjects it to but little impact effect.

The abrasive action of such traffic upon a pavement is great, however, especially if the car is traveling rapidly. When the car passes over any slight unevenness in the pavement it leaves the ground for an instant. The engine races causing the rear or drive wheels to move faster while the front wheels have a tendency to move more slowly. When the car is again on the pavement all four wheels must move at the same rate and the pavement must undergo considerable abrasive wear before this condition is brought about. In addition to this action, automobiles produce partial vacuums behind the wheels which suck the fine particles from the road and cause ravelling. When a wagon passes over a pavement the latter is subjected to the impact of the horses' shoes and of the steel wheels of the vehicle. Consequently it can be seen that the wear in a pavement is due, primarily,to abrasive action and impact. Many ways are available for obtaining either of these effects in the laboratory but it is not so easy to obtain a combination of the two which approximates the actual wear received in a pavement.

Materials.

Coarse Aggregates. - Table I shows the sizes of the coarse aggregate and the percentages of each by weight which were used to make up the coarse aggregate indicated in the tests.

Table I. - Proportions of Different Sizes of Coarse Aggregate Used in Making Majority of Tests.

Sizes of opening in sieves in inches	Percent used by weight.
1/2 - 3/4	33.3
3/4 - 1-1/4	66.7

Two exceptions were made to this rule namely K_j3 and K_j4. The coarse aggregates in these batches were mixed in the following proportions.

Table II. - Proportions of Different Sizes of Coarse Aggregates Used in Making Special Tests.

Batch	Size of opening in sieves in inches		Percent used by weight
K_j3	1/4 - 1/2		14
	1/2 - 3/4		14
	3/4 - 1-1/4		29
	1-1/4 2		43
		Total	100
K_j4	1/4 - 1/2		50
	1/2 - 3/4		50
		Total	100

Fine Aggregates. - Sieve analyses of the fine aggregates were made by shaking a 1000 gram sample for ten minutes in a Ro-Tap automatic shaker with the following results.

Table III. - Sieve Analyses of Sands.

Sieve Numbers	4	8	14	28	48	100	% passing 100
Janesville	8.0	17.4	25.8	40.8	86.0	97.8	2.2
Lohrville Sc.	5.5	22.8	39.7	54.6	70.0	83.2	16.8

Cement. - The cement used in these tests was Universal Portland cement.

Table IV. - Tests of Cement.

Fineness

Residue on #100 sieve = 3 percent

Residue on #200 sieve = 19.2 percent

Vicat test

Time of initial set = 2 hr. 10 minutes

Time of hard set = 5 hr. 35 minutes

Pat test

O.K.

Percentages of Water Used for briquettes

Neat, 22.5 1:3, 9.25 percent

Kind of sand used for briquettes

Standard

Temperature at mixing briquettes

Water 78° F Air 80° F.

Temperature at mixing Compression specimens

Water 77° F Air 78° F.

Tensile strength : Average of three briquettes

Neat	Age	lb./in^2
"	1 day	333
"	7 days	545
"	28 "	603
"	60 "	678
"	180 "	652
1:3	7 "	216
1:3	28 "	310
1:3	60 "	367
1:3	180 "	363

Table IV Cont.

Compressive Strength		Average of 3 cubes
Neat	Age	lb./in^2
"	1 day	2586
"	7 days	5042
"	28 "	6950
"	60 "	7825
"	180 "	7925
1;3	7 "	1146
1;3	28 "	1837
1;3	60 "	2242
1;3	180 "	2565

Description of the Method and Apparatus used.

Reasons for Selecting Present Method.- The present method of testing the specimens was selected for several reasons. First, the abrasion test as here performed closely approximates the actual wear which a pavement receives. Second, this test can be easily made. Third, by testing several different specimens at the same time all are subjected to exactly the same treatment and so a reliable comparison can be made between the different materials. Fourth, the tension and compression tests were made to see if there was any relation between the tensile or compressive strength of the concrete and its resistance to abrasion.

Combining and Proportioning Materials. - Ten different kinds of concrete were made by combining each coarse aggregate with each fine aggregate. Two additional kinds were made by varying the sizes of coarse aggregate as indicated under materials in Table III. All of the concrete was mixed in the proportion of 1:2:3½ by volume.

Mixing. - The mixing was all done by a No. 0 Smith batch mixer. Two batches of each kind of concrete were made. Each batch was mixed one minute dry and two minutes wet at a speed of 28 R.P.M. The concrete was made just wet enough to slide on an oiled plate set at thirty degrees with the horizontal.

Specimens. - Four specimens for the abrasion test and one each for the tension and compression tests were made from each batch. The abrasion specimens were 19-1/2 inches long, 4-3/4 inches thick and 8 inches wide. The compression specimens were cylinders 6 inches in diameter and 12 inches long. The tension specimens were also cylinders 6 inches in diameter and 12 inches long. Three bolts were imbedded for approximately five inches in each end of the tension cylinders. These bolts were spaced symmetrically about the axis of the cylinder so as to give a true axial pull when the cylinders were tested.

Curing. - The specimens were removed from the moulds at the end of twenty-four hours and placed in a moist closet where they were kept damp until 48 hours before they were tested. They were then taken out and allowed to dry in the laboratory until tested at the age of 28 days.

Description of Tension Tests.

The tensile specimens were tested on an Olsen 50,000 - lb. testing machine. Flat steel plates were slipped over the three bolts in each end of the cylinders and the burrs were then put on the bolts. The pull of the machine was transmitted through two bolts held in the pulling heads of the machine, through knife edge bearings to the plates, thence through the plates to the

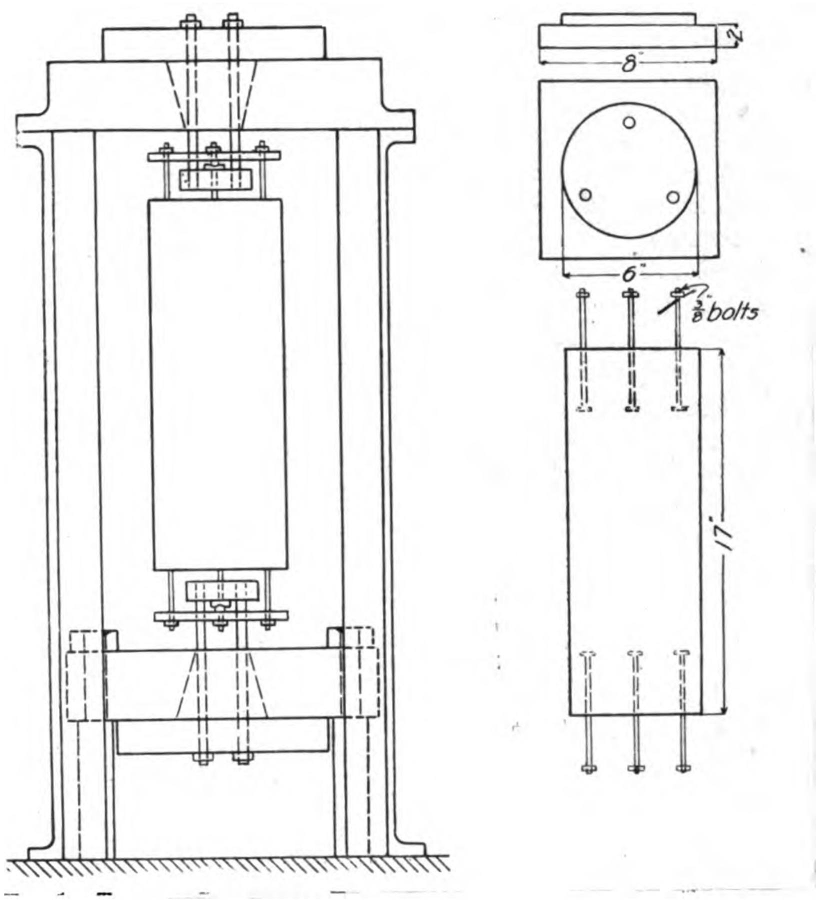


Fig. I.— Tension Specimens—

Templates and Apparatus For Testing.

bolts and through the bolts to the cylinder itself. The knife edge bearings insure an axial pull on the cylinder. Fig. I illustrates the method of testing such specimens more clearly than it can be described.

Description of Compression Tests.- The compression tests were made on a Riehle 100,000 - lb. testing machine. The bearing surfaces were protected by blotting paper which tended to overcome the effect of any slight unevennesses in the surfaces.

Description of Abrasion Tests. - The abrasion tests were made in a Tinius Olsen Rattler from which all but four of the staves had been removed. Seven specimens were tested at one time. The seven blocks were held in the form of a seven sided polygon by means of two metal rings. Wooden blocks were used to wedge the specimens tightly in the rings. A charge of eight large and one hundred and fifty small steel balls was placed inside the polygon and the whole placed in the machine. The weight of the large shot was 58 pounds and of the small shot 142 pounds making a total of 200 pounds. The test consisted of a two hour run at thirty revolutions per minute making a total of 3600 revolutions in all. The amount of wear on the inner surfaces of the blocks was determined by weighing the blocks before and after each run. From this data the percentage of loss in weight of each specimen was calculated. Assuming that the specimens were each 4-3/4 inches thick and using the percentages obtained above the average depth of wear over the entire surface was determined in inches for each block.

Difficulties Encountered and Methods of Overcoming Them. - When work was first begun on these tests, it was intended to make the specimens for the abrasion tests 19-3/4 inches by 6-1/2 inches

by 3 inches, and one batch of blocks was made of this size. At the end of seven days, an attempt was made to test them but they cracked badly and were ruined within fifteen minutes after they were placed in the machine. This showed that the blocks must either be made thicker or reinforced. The former alternative was chosen and the blocks made 4-3/4 inches thick after which no further trouble was experienced.

Considerable difficulty was experienced in getting some of the specimens into the Rattler. This was due to the fact that they were supposed to be 19-3/4 inches long, 8 inches wide and 4-3/4 inches thick whereas the clear distance inside the rattler is 20 inches. The specimens were made in forms composed of channel irons clamped together with wooden blocks to separate the various specimens. When the concrete was placed in the forms, if great care was not taken, the bottoms of these wooden blocks were pushed out slightly so that the two end faces of the blocks were not parallel and the blocks bound when put in the rattler. To overcome this the blocks were made 19-1/2 inches long and but little difficulty was experienced afterward due to this cause.

Sources of Error.- In the computations, it is assumed that all the blocks are exactly 4-3/4 inches thick and the inches of wear computed on this basis. In practice, it is impossible to make the blocks all of exactly the same thickness so that a slight error results in these computations. Further, some variation exists in the speed of the rattler. Consequently, although each set of specimens was run for two hours, due to variability in speed the treatment of the different charges was not uniform but the error

due to this cause is very slight.

In testing the compression specimens some eccentricity of loading probably occurs but this was eliminated so far as possible by the use of spherical compression heads and blotting paper.

In testing the tension specimens eccentric loading was avoided so far as possible by the spacing of the bolts and by pulling through knife edge bearings. An error results in the computations in the tension tests due to the fact that in almost every case the fracture occurred in the plane of the bolt heads and no allowance was made for the decreased area. The error due to this cause is slight as the area of the bolt heads is only about 4 percent of the total cross sectional area of the specimen and the bond between the concrete and iron is nearly equal to the tensile strength of the concrete.

Table V - Key to Marks

J	indicates	Janesville gravel
j	"	" sand
L	"	Lohrville crushed granite
l	"	" " screenings
K	"	Kettle River crushed sandstone
R	"	Racine crushed limestone
M	"	Madison crushed limestone

TABLE VI.

STRENGTH TESTS OF CONCRETE.

Mark	Date Made	Date Tested	Compression Tests. Ultimate Strength lb.	Compression Tests. Lb./in.^{2}	Tension Tests. Ultimate Strength lb.	Tension Tests. Lb./in.^{2}
Jj 2	Mar. 3	Mar. 31	54780	1345	7250	257
Jj 1	Mar. 3	Mar. 31	75650	2655	6170	218
Jl 2	Mar. 5	Mar. 31	38900	1376	5200	184
Jl 3	Mar. 17	Apr. 14	42940	1520	6290	223
Kj 1	Mar. 8	Apr. 3	42425	1500	5050	179
Kj 2	Mar. 9	Apr. 6	47860	1695	4900	173
Kl 1	Mar. 9	Apr. 6	33380	1182	6000	212
Kl 2	Mar. 17	Apr. 14	52000	1840	5480	194
Ll 1	Mar. 19	Apr. 16	47050	1665	4050	143
Ll 2	Mar. 19	Apr. 16	32700	1158	5675	201
Rl 1	Mar. 24	Apr. 21	45250	1600	5125	181
Rl 2	Mar. 24	Apr. 21	46420	1644	6760	239
Lj 1	Mar. 24	Apr. 21	49900	1767	7195	254
Lj 2	Mar. 24	Apr. 21	41200	1457	4335	153
Rj 1	Mar. 29	Apr. 26	65300	2310	7650	271
Rj 2	Mar. 29	Apr. 26	65070	2300	7380	261
Ml 1	Mar. 29	Apr. 26	60500	2140	5970	211
Ml 2	Apr. 28	May 26	55000	1945	6620	234
Mj 1	Apr. 28	May 26	76050	2690	8490	301
Mj 2	Apr. 28	May 26	61000	2160	5720	202
Kj 3	May 2	May 29	40740	1442	2285	81
Kj 4	May 3	May 29	53475	1894	3820	135

* * *

TABLE XVI Results of Abrasion Tests.

Mark	Weight before	Weight after	Loss Lbs.	Loss Percent	Loss in inches of thickness.
Jj 11	70.5	64.7	5.8	8.2	.330
Jj 12	68.7	64.3	4.4	6.4	..304
Jj 13	69.7	64.8	4.9	7.0	.332
Jj 14	70.2	63.8	6.4	9.1	.432
Averages				7.7	.366
Jj 21	65.4	60.4	5.0	7.6	.361
Jj 22	67.9	63.0	4.9	7.2	.342
Jj 23	67.1	61.6	5.5	8.2	.389
Averages				7.7	.366
Jl 21	60.5	55.8	4.7	7.8	.370
Jl 22	65.9	69.3	6.6	9.3	.442
Jl 23	64.3	58.3	6.0	9.3	.442
Averages			6.4	8.8	.418
Jl 31	66.1	61.3	4.8	7.27	.345
Jl 32	69.2	63.7	5.5	7.96	.378
Jl 33	68.6	63.7	4.9	7.15	.340
Jl 34	65.8	60.2	5.6	8.52	.404
Averages				7.725	..367
Kj 11	61.8	55.7	6.1	9.87	.468
Kj 12	62.3	59.2	3.1	4.98	.236
Kj 13	62.0	57.3	4.7	7.53	.360
Kj 14	62.8	58.4	4.4	7.00	.332
Averages				7.36	.349
Kj 21					
Kj 22	64.8	60.2	4.6	7.1	.337
Kj 23	63.2	53.0	4.2	6.65	.316
Kj 24	61.4	57.5	3.9	6.36	.302
Averages				6.74	.320
Kl 11	61.5	58.6	2.9	4.72	.224
Kl 12	61.0	57.9	3.1	5.08	.241
Kl 13	62.1	59.5	2.6	4.18	.199
Kl 14	61.4	58.2	3.2	5.22	.248
Averages				4.80	.228
Kl 21	59.7	55.6	4.1	6.87	.326
#Kl 22	59.1	53.1	6.0	10.15	.482
Kl 23	62.0	58.2	3.8	6.13	.291
Kl 24	62.0	58.6	3.4	5.48	.260
Averages				6.17	.298

#Not tested at 28 days

TABLE VII (Continued)

Mark	Weight before	Weight after	Loss Lbs.	Loss percent	Loss in inches of thickness
L1 11	64.2				
L1 12	64.6	59.3	5.3	8.21	.390
L1 13	65.5	61.0	4.5	6.87	.326
L1 14	62.8	57.6	5.2	8.28	.393
	Averages			7.79	.370
L1 21	65.7	61.2	4.5	6.86	.326
L1 22	65.0	59.6	5.4	8.32	.395
L1 23	64.3	59.8	4.5	7.00	.332
L1 24	64.9	60.1	4.8	7.40	.351
	Averages			7.23	.343
R1 11	63.7	59.5	4.2	6.60	.313
R1 12	65.3	61.2	4.1	6.28	.298
R1 13	65.5	61.4	4.1	6.27	.297
#R1 14	65.1	61.1	4.0	6.16	.292
	Averages			6.38	.303
R1 21	62.5	58.2	4.3	6.88	.327
R1 22	64.0	59.0	5.0	7.82	.371
R1 23	65.1	59.9	5.2	7.99	.379
R1 24	64.2	60.3	3.9	6.08	.289
	Averages			7.19	.341
Lj 11	68.5	65.6	2.9	4.23	.201
Lj 12	67.7	64.1	3.6	5.32	.253
Lj 13	66.4	62.6	3.8	5.72	.271
Lj 14	68.5	64.9	3.6	5.26	.250
	Averages			5.13	.244
Lj 21	68.0	61.0	7.0	10.3	.488
Lj 22	64.9	52.1	12.8	19.7	.935
Lj 23	64.9	54.1	10.8	16.6	.788
Lj 24					
	Averages			15.53	.737
Rj 11	67.9	64.2	3.7	5.45	.259
Rj 12	68.9	64.9	4.0	5.81	.276
Rj 13	68.0	63.7	4.3	6.32	.300
Rj 14	70.3	66.6	3.7	5.27	.250
	Averages			5.71	.271
Rj 21					
Rj 21	65.3	61.6	3.7	5.67	.269
Rj 22	66.3	62.7	3.6	5.42	.257
Rj 23	66.8	63.2	3.6	5.39	.256
Rj 24	67.3	63.9	3.4	5.05	.240
	Averages			5.38	.255

TABLE VII (Concluded)

Mark	Weight before	Weight after	Loss Lbs.	Loss percent	Loss in inches of thickness.
Ml 11	66.2	63.5	2.7	4.08	.134
Ml 12	64.0	60.6	3.4	5.32	.252
Ml 13	63.1	60.3	2.8	4.43	.210
Ml 14	63.3	60.5	2.8	4.92	.210
	Averages			4.56	.216
Ml 21	66.5	61.4	5.1	7.56	.353
Ml 22	64.6	60.3	4.3	6.67	.316
Ml 23	65.4	61.0	4.4	6.72	.313
Ml 24	64.9	60.1	4.8	7.40	.356
	Averages			7.09	.336
Mj 11	66.1	61.3	4.8	7.27	.345
Mj 12	66.1	63.3	2.8	4.23	.201
Mj 13	68.7	64.0	4.7	6.85	.278
Mj 14	67.4	63.0	4.4	6.53	.310
	Averages			6.22	.295
Mj 21	65.4	61.0	4.4	6.72	.319
Mj 22	63.8	60.8	3.0	4.70	.223
Mj 23	67.7	63.0	4.7	6.94	.329
Mj 24	65.7	60.7	5.0	7.62	.361
	Averages			6.50	.309
Kj 31	62.6	57.6	5.0	8.00	.380
Kj 32	64.6	61.1	3.5	5.42	.257
Kj 33					
Kj 34	62.6	59.1	3.5	5.58	.265
	Averages			6.33	.301
Kj 41	60.9	56.6	4.3	7.07	.336
Kj 42	62.0	54.8	7.2	11.62	.552
Kj 43	57.5	53.4	4.1	7.13	.339
Kj 44	58.1	52.7	5.4	9.30	.442
	Averages			8.78	.417

TABLE VIII Comparison of Average Results of the different Tables (Materials arranged in order of Resistance)

Compression		Tension		Abrasion	
Materials	Strength lb./in.^{2}	Materials	Strength lb./in.^{2}	Materials	Average Wear, in.
Mj	2425	Rj	266	Lj	.244
Rj	2305	Mj	252	Kl	.264
Jj	2300	Jj	238	Rj	.263
Ml	2042	Ml	223	Ml	.276
Rl	1622	Rl	210	Mj	.302
Lj	1612	Lj	204	Rl	.322
Kj	1598	Jl	204	Kj	.334
Kl	1511	Kl	203	Ll	.356
Jl	1448	Kj	176	Jj	.366
Ll	1411	Ll	172	Jl	.392

Average Abrasive Resistance of Concretes made with Different coarse Aggregates.

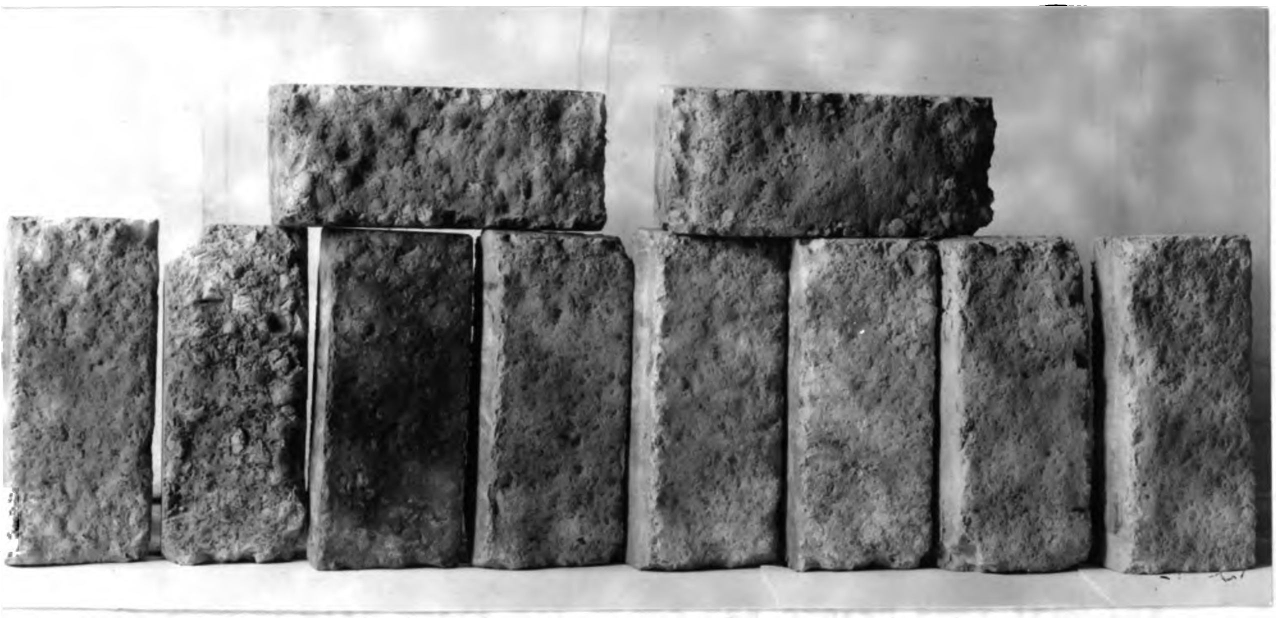
Material	Average Wear, in.
M	.283
R	.292
K	.299
L	.300

Average Abrasive Resistance of Concretes made with Janesville Sand and Lohrville Screenings.

Material	Average Wear, in.
Janesville Sand	.302
Lohrville Screenings	.322

Table 9. - Specific Weights of Aggregates Used in Tests

Material	Specific Weight lb./ft^3
j	107
1	105
J	94.5
K	79.6
R	85.0
L	80.5
M	80.0
K_3	87,5
K_4	78.8
Cement	94.0



Lj 11   Lj 23   Kj 23   Kj 14   Rj 24   Rj 12   Mj 11   Mj 21

Jj 21   Jj 13

Fig.2.- Showing Results of Abrasion Tests on Concretes Made from Janesville Sand and Various Coarse Aggregates.

Report on Condition of the Specimens

Abrasion Tests. - The condition of the specimens subjected to the abrasion test can be more clearly seen from the photographs than from a description of them. Some little discussion of their condition is, however, advisable. Fig. II shows the results of tests on concretes made with various coarse aggregates combined with Janesville sand, a representative specimen being taken from each batch.

The two batches made from Lohrville granite show widely differing resistances to wear. The blocks of the first batch show the least wear of any and have maintained a comparatively smooth surface while the blocks of the record batch have worn the most of any of those tested. The corners were knocked off these specimens and they show pits where the stone has broken away from the mortar. In other places the stone appears to have crushed and split off.

The Kettle River specimens show a comparatively smooth surface with the stone wearing down with the mortar instead of kicking out.

The Racine specimens appear to wear the most uniformly of any of those tested. They show but slight wear and the stone has worn down evenly with the mortar.

The specimens made from the Madison stone show a slight and comparatively even wear.

The Janesville gravel specimens show pit holes where the gravel has been knocked loose from the mortar. These pit holes cause the surface to wear rapidly and become very uneven.

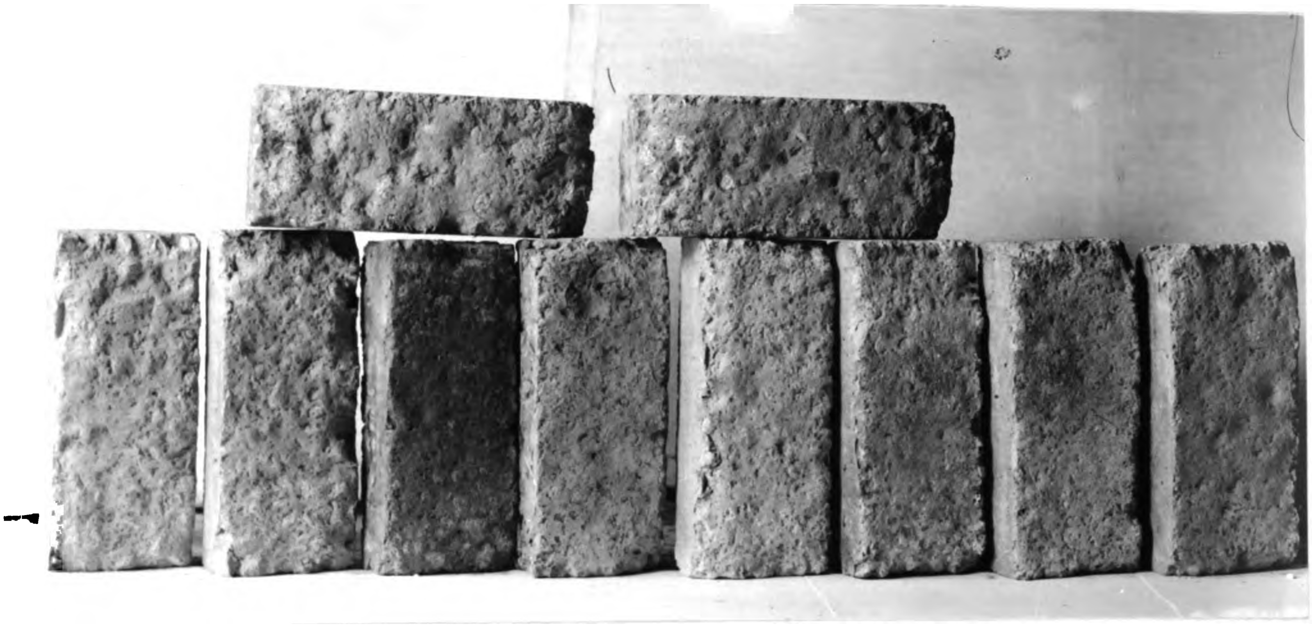


Fig.3. - Showing Results of Abrasion Tests on Concretes Made from Lohrville Screenings and Various Coarse Aggregates.

Fig.III shows the results of tests on concretes made with various coarse aggregates combined with Lohrville screenings, a representative specimen being taken from each batch.

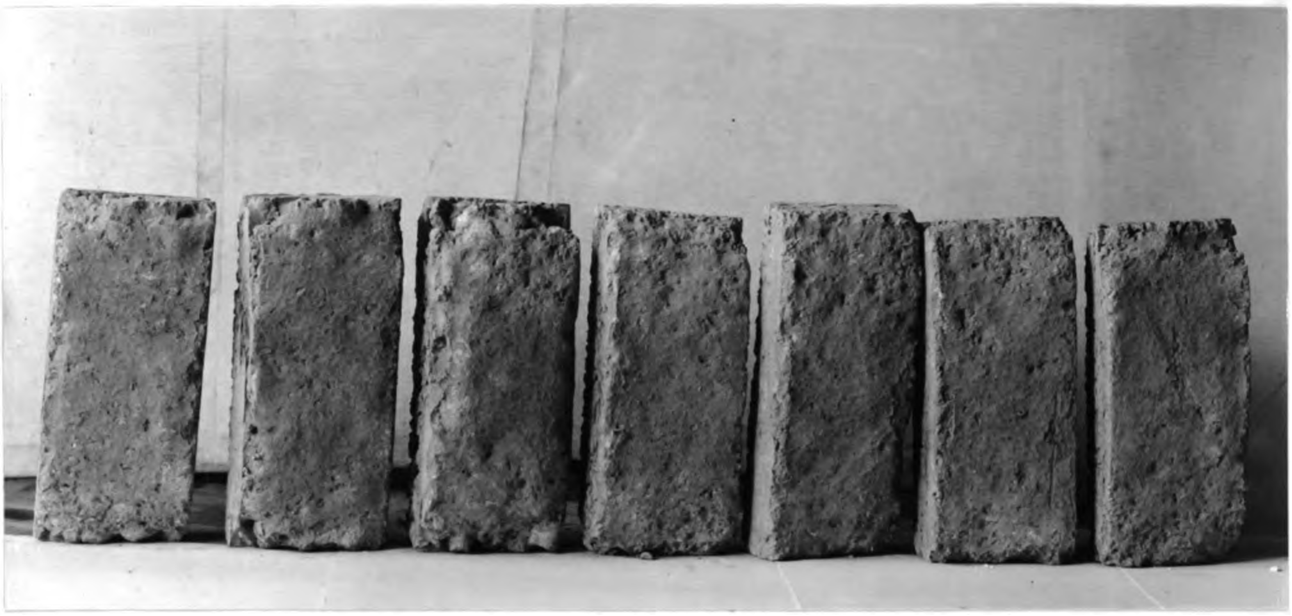
The Lohrville specimens show considerable wear but the surface is comparatively smooth showing that the wear has been uniform and that the stone has not kicked out much.

The Kettle River specimens show a quite even surface, the stone wearing evenly with the mortar. These specimens on the whole appear to have withstood the abrasion test the best of any of those tested.

The specimens made from Racine stone show a comparatively even surface with a medium amount of wear.

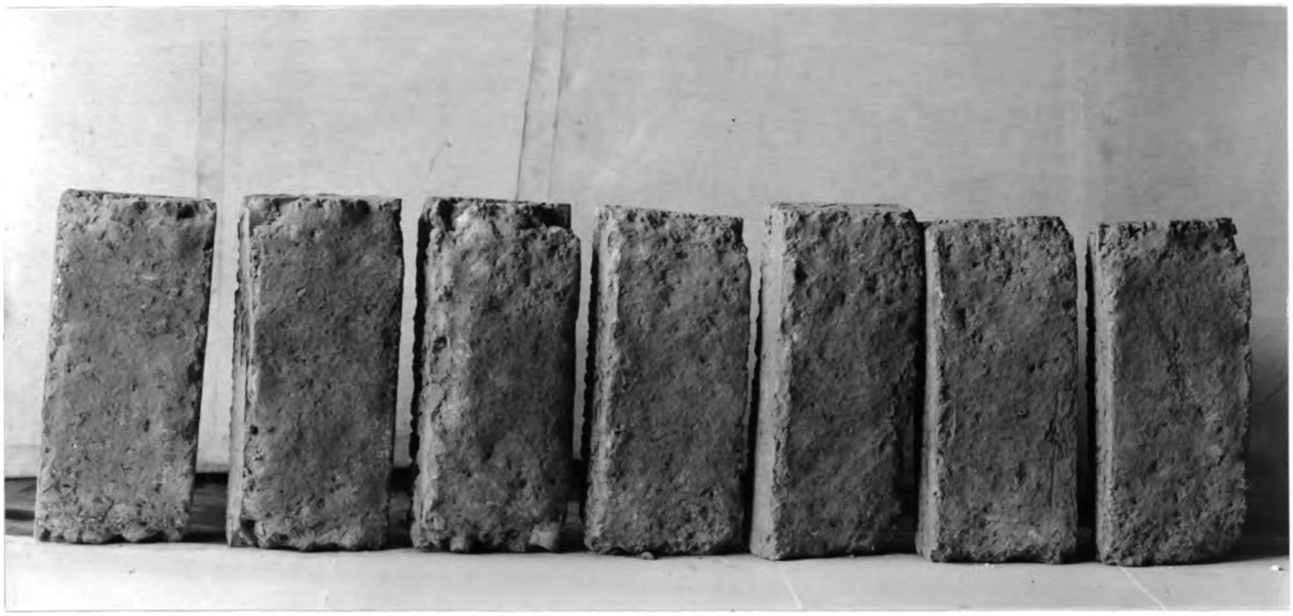
The specimens made from the Madison stone have an exceptionally smooth surface and show but little wear.

The Janesville gravel specimens were badly worn. The surfaces of these blocks were uneven, many of the stones having been knocked out. These pit holes can be seen on block number (j 1 33) in Fig.III.



Kj 34 Kj 32 Kj 31 Kj 43 Kj 42 Kj 41 Kj 44

Fig. 4. - Showing Results of Abrasion Tests on Concretes Made from Janesville Sand and Various Sizes of Kettle River Sandstone.



Kj 34 Kj 32 Kj 31 Kj 43 Kj 42 Kj 41 Kj 44

Fig. 4. - Showing Results of Abrasion Tests on Concretes Made from Janesville Sand and Various Sizes of Kettle River Sandstone.

Fig.IV shows the results of tests on concretes made with different sizes of coarse aggregate. The three specimens on the left were made from Kettle River sandstone, ranging in size from 1/4 of an inch to 2 inches, and Janesville sand. The four blocks on the right were made from Kettle River sandstone varying in size from 1/4 inch to 3/4 inch and Janesville sand. The blocks were made as nearly alike as possible in other respects. Those containing the coarser stone seem to have worn more uniformly than the others which have worn considerably at the ends.

Tension Tests. - In testing the tension cylinders, cylinder (Mj1) was the only specimen which did not break in the plane of the bolt heads.

Cylinder (Mj2) was a poor specimen as one of the bolts was placed too near the surface and pulled out at a load of 3850 lbs. This cylinder failed completely at a load of 5720 lbs. but the one bolt pulling out made the loading eccentric so that the tension test on this block is of little value.

The specimen (Kj3) was also a poor specimen as it was improperly tamped and the bolts slipped during the test.

Conclusions

The relative durability of different concretes when subjected to abrasion and impact seems to depend not alone upon the coarse aggregate or upon the fine aggregate used but upon the combination of the two as some of the coarse aggregates show less wear when combined with sand while others show less wear when combined with screenings. These facts are more clearly brought out by reference to Fig.V where the average results of the different tests with each combination of aggregates are plotted against the different aggregates. These curves indicate a relation between the tensile and compressive strengths of the same kind of concrete but neither of these seem to bear to bear any relation to the resistance to abrasion and impact. The curves shown in Fig.V indicate that sand gives a higher tensile or compressive stress than screenings when combined with the same coarse aggregate.

The abrasion tests made show that for the different materials used the concrete in which broken stone is used wears better

than that in which gravel is used. This seems to be due to the non-uniformity in hardness of the gravel. The mortar wears out from between the harder pebbles and then they are loosened and come out leaving holes in the specimen. The impact then rapidly wears away the specimen around the edges of these holes causing the surface to become very uneven.

The softer stones seem to give better results than the harder ones as they wear down more evenly and so are less affected by impact.

It is the opinion of the writers that this method of testing concrete is a more reliable indication of its durability in a pavement than the tests of hardness and compressive strength which are now in use. Should this belief be substantiated by further tests, this work may aid in bringing into use certain classes of stone which have heretofore been considered of little value.

1 inch = $\frac{1}{10}$ inch of Abrasive Wear
1 inch = 1000 lbs. per. in² Compressive Strength
1 inch = 100 lbs. per. in² Tensile Strength

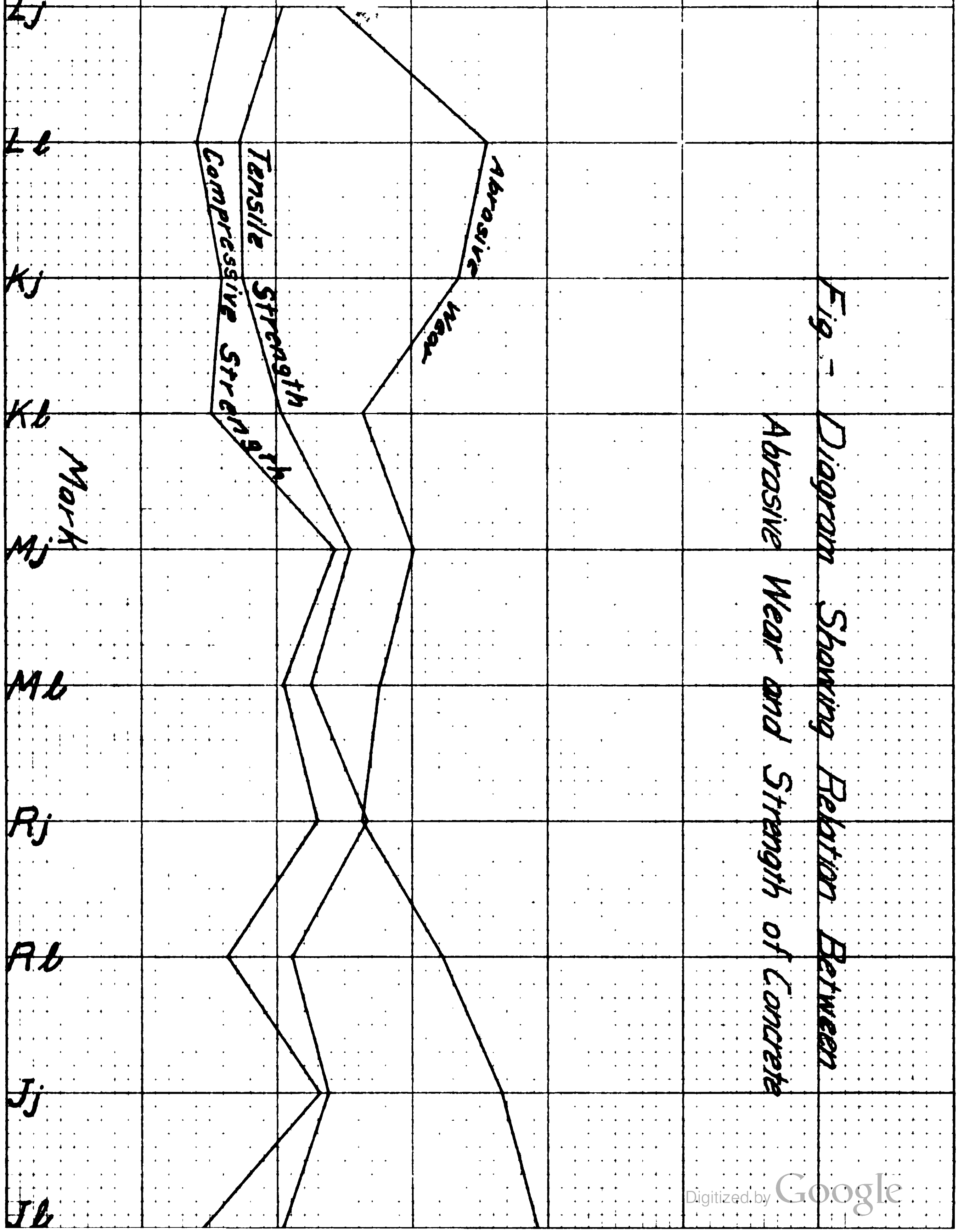


Fig. - Diagram Showing Relation Between Abrasive Wear and Strength of Concrete

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant it s acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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